LA-UR -85-2265

RECEIVED BY R&D
CONF - 850827 - 4
MAY 05 1985

MASTER

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-24

LA-UR--85-2265

DE85 014074

TITLE: PRELIMINARY INVESTIGATION OF CHANGES IN X-RAY MULTILAYER
OPTICS SUBJECTED TO HIGH RADIATION FLUX

AUTHOR(S): M. P. Hockaday M. M. Klein
R. L. Blake W. Matuska, Jr.
J. S. Grosso M. A. Palmer
M. M. Selph R. J. Liefeld

SUBMITTED TO: SPIE's 29th Annual International Technical Symposium
Town & Country Hotel
San Diego, California

August 18-23, 1985

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Preliminary investigation of changes in x-ray multilayer optics
subjected to high radiation flux

M. P. Hockaday, R. L. Blake, J. S. Grosso and M. M. Selph

Physics Division, Los Alamos National Laboratory
Mail Stop D410, P. O. Box 1663, Los Alamos, New Mexico 87545

M. M. Klein and W. Matuska, Jr.

Applied Theoretical Physics Division, Los Alamos National Laboratory
Mail Stop F669, P. O. Box 1663, Los Alamos, New Mexico 87545

M. A. Palmer

Sandia National Laboratories
P. O. Box 5800, Albuquerque, New Mexico 87185

R. J. Liefeld

Physics Department, New Mexico State University
P. O. Box 30, Las Cruces, New Mexico 88003

Abstract

A variety of metal multilayers was exposed to high x-ray flux using Sandia National Laboratories' PROTO II machine in the gas puff mode. Fluxes incident on the multilayers above 700 MW/cm^2 in total radiation, in nominal 20 ns pulses, were realized. The neon hydrogen- and helium-like resonance lines were used to probe the x-ray reflectivity properties of the multilayers as they underwent change of state during the heating pulse. A fluorescer-fiber optic-streak camera system was used to monitor the changes in x-ray reflectivity as a function of time and irradiance. Preliminary results are presented for a W/C multilayer. Work in progress to model the experiment is discussed.

Introduction

The possibility of varying the 2d-spacing of metal multilayer x-ray diffraction elements in the range of 20 - 200 angstroms makes them good candidates for high temperature plasma x-ray spectroscopy.¹ As higher temperatures are reached in plasmas, questions arise concerning the resultant heat load on the diagnostics themselves. This paper discusses our on-going research into the resultant heat loading of metal multilayers exposed to high radiation flux from plasmas with 10 - 30 ns x-ray radiation pulse widths and approximately 20 J/cm^2 surface dose.

The source and experiment

The PROTO II accelerator at Sandia National Laboratories, Albuquerque, was used to implode annular gas puffs of neon gas.² In addition to the pure gas shots, gas puffs were imploded upon targets of polyacrylic acid foam and perylene soda straws. The resultant radiation that was produced can be characterized as having a low energy recombination continuum and characteristic line radiation of neon and of the impurities in the system. Around 1 keV, radiation is primarily in the H- and He-like resonance lines of neon as shown in Figure 1. The fact that there is practically nothing except the two resonance lines near 1 keV made this spectral source ideal for the heat loading problem. The neon resonance lines could be used to probe the changes in the x-ray reflectivity of the metal multilayers.

The total energy, the temporal FWHM, and the size of the plasma column exhibited shot-to-shot variation depending on the target the gas was imploded upon and machine parameters. The total energy of the H- and He-like resonance lines emitted from an approximate 4 mm diameter by 2 cm long source in 4 π steradians was 1 to 2 kJ in each line, with a temporal FWHM of approximately 20 ns. A typical source emitting ~ 1 keV and above radiation is shown in Figure 2. The low energy radiation is emitted from a smaller volume of 2 mm in diameter and 2 cm in length. The total energy in 4 π steradians for all radiation was in the 20 - 40 kJ range.

The experiment consisted of two metal multilayer spectrometers. Each spectrometer had provisions for a prefilter, a metal multilayer diffraction element, a post filter, a NE110 fluor and a fiber optic bundle coupled to a shared visible streak camera. Spectrometer 1 was designed to have the metal multilayer located 150 cm from the source; at this distance

it would diffract the incident radiation without undergoing any physical change. Therefore, Spectrometer 1 provided the "control" spectrum. Spectrometer 2 was designed such that the metal multilayer was only 15 cm from the plasma center and was expected to experience physical changes during the radiation pulse. These physical changes could be detected by comparing the differences in reflected spectra from the two spectrometers. Figure 3 is a schematic of the two spectrometers and their relationship to the source. Both spectrometers were 75 degrees off the cylindrical axis of the plasma.

In addition to the two metal multilayer spectrometers, there were a variety of other plasma diagnostics on each shot, including a curved YAP crystal spectrograph, a grazing incidence spectrograph, several pinhole cameras, time resolved bolometers and several x-ray diodes (XRD). The additional diagnostics allow us to know the spectrum and the total energy incident on the multilayer. This is especially important if one is to quantify the changes in the multilayer and to do the modeling.

The separations of the individual spectrometer components were determined by the physical constraints of the existing vacuum system of PROTO II. The available angular width coupled with the distance at which one could place items of considerable width outside the vacuum system were of particular importance. The Bragg angle of the metal multilayers had to be less than 11 degrees in order to prevent the multilayer at source distance 15 cm from blocking other lines of sight, and to diffract the relevant x-rays out the available port. The constraints on the Bragg angle set the possible 2d-spacings of the multilayers that could be used in the experiment. Specifically, for 1 keV radiation the 2d-spacing could not be less than 71.5 angstroms. It was determined that the spectrometers would be designed for nominal Bragg angles of 5 and 10 degrees. Therefore, the two 2d-spacings to be investigated would be ~ 70 angstroms and ~ 140 angstroms. Metal multilayers of W/C, Mo/C and Pd/C obtained from Troy Barbee of Stanford University and multilayers from Ovonics Synthetic Materials Co. of W/C and W/Si were used as samples. Emphasis was given to the W/C multilayers. Each metal multilayer had its diffraction profile measured at Cu L_{α} in the laboratory before and after being subjected to heat loading.

The fluorescer used was NE1110, which has a temporal response FWHM of 1.9 ns at 390 nm⁹ with a spectral FWHM of ~ 50 nm.⁹ The fiber bundle was constructed from Corning DBF 95 μ m diameter core and 125 μ m outer diameter fiber which has a dispersion of ~ 30 ps/(nm-100 ft) at 390 nm. The bundle was 47 meters in length and was fabricated by EG&G, Las Vegas. To have a reasonable intrinsic FWHM system it was necessary to use a BARR® interference filter with peak transmission of 74%, centered at 380 nm with a spectral FWHM of 20 nm decreasing the effective FWHM of the NE1110 light to 20 nm. The resultant effective system temporal FWHM was 2.4 ns. The fiber bundle itself consisted of 219 fibers. Sixty-four (64) fibers covered the detection plane of Spectrometer 1 in a linear coherent array. The detection plane of Spectrometer 2 was covered by two sets of 56 fibers separated by a 6 mm gap in the plane of dispersion. The difference in the number of fibers necessary to cover the two detection planes was due to the different distances of the detection planes from their respective multilayer diffraction elements. Four fibers were used for comb and impulse fiducials.

The streak camera was an EG&G Modular Streak Camera with a 3 cm photocathode. A GEN2 MCP image intensifier was used to increase the signal. Data were taken on KODAK® Royal X-Pan film. An EG&G H-OE-28 Optical Comb Generator was used to input light pulses at 2 ns intervals into 3 temporal calibration fibers.

Data

At the time of writing, data analysis had just begun. We will report, however, one striking trend in the data. Specifically, we will discuss Shot No. 1863 which was a pure neon gas puff. Thin film bolometer data from D. L. Hanson indicates an isotropic yield of 43.4 kJ of total radiation with 15.3 kJ in line radiation. Figure 2 is the pinhole photograph for Shot No. 1863 showing the extent of the plasma emitting around 1 keV.

The metal multilayers fielded were two pieces cut from the same sample of OVLA130B from Ovonics Synthetic Materials, Co.; a W/C of 134 angstroms 2d. One hundred twenty-three (123) μ g/cm² of Al were used as a postfilter for each spectrometer. There were no prefilters involved. The streak camera data were digitized at EG&G on a Perkin Elmer PDS Microdensitometer. Corresponding signals for the same feature for each spectrometer are shown in Figure 4. The data have been smoothed using an adaptive filtering code called AWARE.¹

The signal from Spectrometer 1 is larger than that of Spectrometer 2 even though it was 10 times farther from the source, in part, because Spectrometer 1 exhibits higher background exposure due to its more straight-through line of sight. Also, the time history of the signal from Spectrometer 2 cuts off very quickly, even before the main peak of the radiation

pulse. A great difference in the FWHM of the two signals is evident. The signal from Spectrometer 1 has a FWHM of ~ 25 ns which is in agreement with the value given by a corresponding XRD (R. B. Spielman, Sandia National Laboratories). The signal from Spectrometer 2 exhibits a FWHM of only ~ 2 ns and falls off very rapidly, indicating that the multilayer reflecting surface was destroyed before the peak of the keV radiation pulse.

Modeling in progress

Many approaches exist for calculating metal multilayer x-ray diffraction properties. These include the closed form Darwin Prins calculations,¹⁰ recursion relation method,¹¹ and the matrix method from E&M boundary conditions.¹² Because the matrix method is compatible with the zoning techniques of existing Los Alamos hydrodynamics codes, it is thus used in our analysis. Instead of having each matrix describe a layer, we have a matrix describe each zone. This can be part of a layer or a whole layer, allowing us to follow material flow, and expansion and contraction inside the multilayer more readily. The optical constants α and β , the real and imaginary parts of the index of refraction, needed for the matrix method are calculated according to Henke, et al¹⁰ using the atomic form factors in Henke, et al¹¹ and extended by Auerback and Firrell.¹²

When a multilayer is subjected to high radiation flux, one would expect the layers to absorb the radiation differentially depending upon the material properties of the particular layer and its position in the stack. Using the matrix method, and following Berning,¹³ it is straight forward to calculate the energy deposited in each zone or layer using the matrix method.

The data from the XRDs and thin film bolometers determine the power of the incident spectrum as a function of time. The four necessary components for modeling the problem are now in place. We can calculate the reflectivity of the multilayer, determine the energy absorbed from the incident spectrum, and then determine the changes in the multilayer according to hydrodynamics for a time step. We reiterate the process until we have followed the incident spectrum through its cycle. We will then be able to compare the model with the experimental data described above.

Summary

We have outlined our on-going project to investigate the heat loading effects on metal multilayers irradiated by extreme fluxes from high temperature plasmas. The desired experimental results have been obtained and modeling is under way.

Acknowledgments

We wish to thank the PROTO II experimental team and machine crew, and EG&G for their assistance. This work was supported by the Department of Energy.

References

1. R. W. Day and T. W. Barbee, "Application of Layered Synthetic Microstructures to High Temperature Plasma Diagnostics," presented at 9th Topical Conference on High Temperature Diagnostics, Granlibakken Resort, Tahoe City, California (September 16-20, 1984).
2. R. B. Spielman, D. L. Hanson, M. A. Palmer, M. K. Matzen, T. W. Hussey, and J. M. Peak, "Efficient X-Ray Production from Ultrafast Gas-Puff Z-Pinches," J. Appl. Phys., **57**, 830 (1985).
3. R. Day, J. Grosso, R. Bartlett, and T. Barbee, "Layered Synthetic Microstructures: Measurements and Applications," Nucl. Instrum. and Methods Phys. Rev. (Netherlands), Vol. 208, No. 1-3, 245 (1983).
4. S. S. Lutz, L. A. Franks, J. M. Fluoroy, and P. B. Lyons, "Scintillators for Fiber Optics: System Sensitivity and Bandwidth as a Function of Fiber Length," SPIE Fiber Optics in Adverse Environments, Vol. 296, 156 (1981).
5. J. G. Pronko, T. R. Fisher and L. F. Chase, "Scintillator Response Characteristics to Low Energy X-Rays," OSA 4766F, (1978).
6. L. P. Mix, E. J. Y. Burns, D. L. Fehl, D. L. Hanson, and D. J. Johnson, "Low Energy X-Ray Emission from Light Ion Targets," in Proceedings of the Conference on Low Energy X-Ray Diagnosis, Monterey, California (American Institute of Physics, New York, 1981), Inst. Phys. Conf. Ser. No. 75, p. 25.
7. E. K. Hodson, D. R. Thayer, and C. Franklin, "Adaptive Gaussian Filtering and Local Frequency Estimates Using Local Curvature Analysis," in IEEE Transactions on Acoustics, Speech, and Signal Processing, Vol. ASSP-29, 854 (1981).
8. P. Lee, "X-Ray Diffraction in Multilayers," Opt. Commun., **37**, 159 (1981).
9. J. M. Underwood and T. W. Barbee, Jr., "Synthetic Multilayers as Bragg Diffractors for X-Rays and Extreme Ultraviolet: Calculations of Performance," in Proceedings of the Conference on Low Energy X-Ray Diagnosis, Monterey, California (American Institute of Physics, New York, 1981), Inst. Phys. Conf. Ser. No. 75, p. 170.
10. B. L. Henke, *Ibid.*, p. 142.
11. B. L. Henke, P. Lee, T. J. Tanaka, R. L. Shimabukuro and B. K. Fujikawa, Atomic Data and Nuclear Data Tables, **27**, 1 (1982).
12. J. A. Auerback and K. G. Firrell, UCRL-Report No. 91230, (1984).
13. P. M. Berning, "Theory and Calculations of Optical Thin Films," Phys. Thin Films, **1**, 49 (1963).

Figure 1. Typical neon spectrum, emitted by the source obtained with a KAP convex-curved spectrograph.

Figure 2. Spot 1263 (neon): x-ray pinhole photograph resulting from exposure to x rays above keV. (RAR 2497 film, beryllium entrance window; line of sight 75 degrees off cylindrical axis).

Figure 3. Schematic of components of the two multilayer spectrometers. Geometry was constrained to fit the vacuum system of PROTO II.

Figure 4. Compressed streak from Spectrometers 1 and 2. Data were smoothed using AWARE adaptive filtering code in exposure space.